

TECHNICAL NOTES

April 3, 2000

MO-1 Technical Note Number 28

Re: Manuscripts - Handling References in Manuscripts

To eliminate the need for tedious cross-checking and renumbering, sources in the references list do not need to be numbered. The sources are cited in the text by author and date instead of by number. Attached is a sample reference list without numbers and text that includes a citation for each of the references included in the list.

General rules for citing the sources in the text are as follows:

1. For references with a single author, the last name of the author and the date are given in parentheses in the text. Examples are (Baldwin, 1976) and (Society of American Foresters, 1980).
2. If there is more than one reference with the same author and same date, add a small letter "a," "b," and so on as needed after the date. Examples are (Alexander, 1967a) and (Alexander, 1967b).
3. For references that have two authors, the last name of both of the authors is cited in the text. For example, (Dixon and Weed, 1977).
4. For references that have more than two authors, use only the last name of the first author listed in the reference and "and others" or "et al." Examples are (Peterson et al., 1976) and (Buol and others, 1973).
5. Authors such as United States Department of Agriculture, American Association of State Highway and Transportation Officials, and American Society for Testing and Materials can be abbreviated in the text if the users will readily recognize the abbreviations. Examples are (USDA, 1961), (AASHTO, 1986), and (ASTM, 1993).

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How This Survey Was Made

This survey was made to provide information about the soils and miscellaneous areas in the survey area. The information includes a description of the soils and miscellaneous areas and their location and a discussion of their suitability, limitations, and management for specified uses. Soil scientists observed the steepness, length, and shape of the slopes; the general pattern of drainage; the kinds of crops and native plants; and the kinds of bedrock. They dug many holes to study the soil profile, which is the sequence of natural layers, or horizons, in a soil. The profile extends from the surface down into the unconsolidated material in which the soil formed. The unconsolidated material is devoid of roots and other living organisms and has not been changed by other biological activity.

The soils and miscellaneous areas in the survey area are in an orderly pattern that is related to the geology, landforms, relief, climate, and natural vegetation of the area. Each kind of soil and miscellaneous area is associated with a particular kind of landform or with a segment of the landform. By observing the soils and miscellaneous areas in the survey area and relating their position to specific segments of the landform, a soil scientist develops a concept or model of how they were formed. Thus, during mapping, this model enables the soil scientist to predict with a considerable degree of accuracy the kind of soil or miscellaneous area at a specific location on the landscape.

Commonly, individual soils on the landscape merge into one another as their characteristics gradually change. To construct an accurate soil map, however, soil scientists must determine the boundaries between the soils. They can observe only a limited number of soil profiles. Nevertheless, these observations, supplemented by an understanding of the soil-vegetation-landscape relationship, are sufficient to verify predictions of the kinds of soil in an area and to determine the boundaries.

Soil scientists recorded the characteristics of the soil profiles that they studied. They noted color, texture, size and shape of soil aggregates, kind and amount of rock fragments, distribution of plant roots, reaction, and other features that enable them to identify soils. After describing the soils in the survey area and determining their properties, the soil scientists assigned the soils to taxonomic classes (units). Taxonomic classes are concepts. Each taxonomic class has a set of soil characteristics with precisely defined limits. The classes are used as a basis for comparison to classify soils systematically.

Soil taxonomy, the system of taxonomic classification used in the United States, is based mainly on the kind and character of soil properties and the arrangement of horizons within the profile. After the soil scientists classified and named the soils in the survey area, they compared the individual soils with similar soils in the same taxonomic class in other areas so that they could confirm data and assemble additional data based on experience and research.

While a soil survey is in progress, samples of some of the soils in the area generally are collected for laboratory analyses. Soil scientists interpret the data from these analyses and tests as well as the field-observed characteristics and the soil properties to determine the expected behavior of the soils under different uses. Interpretations for all of the soils are field tested through observation of the soils in different uses and under different levels of management. Data are assembled from other sources, such as research information, production records, and field experience of specialists.

Predictions about soil behavior are based not only on soil properties but also on such variables as climate and biological activity. Soil conditions are predictable over long periods of time, but they are not predictable from year to year. For example, soil scientists can predict with a fairly high degree of accuracy that a given soil will have a high water table within certain depths in most years, but they cannot predict that a high water table will always be at a specific level in the soil on a specific date.

After soil scientists located and identified the significant natural bodies of soil in the survey area, they drew the boundaries of these bodies on aerial photographs and identified each as a specific map unit. Aerial photographs show trees, buildings, fields, roads, and rivers, all of which help in locating boundaries accurately.

Survey Procedures

The general procedures followed in making this survey are described in the National Soil Survey Handbook of the Natural Resources Conservation Service. Source material used in the development of the survey includes the soil survey of the Deschutes Area, Oregon (USDA, 1958); the interim soil survey of the Brothers Area (USDI, 1983); U.S. Geological Survey geologic maps; and the National Cooperative Soil Survey memorandum of understanding between the Natural Resources Conservation Service, the Forest Service, the Bureau of Land Management, and the Oregon Agricultural Experiment Station.

By separating the landscapes into discrete

landforms and identifying the dominant soil-forming properties on each landform, predictable soil-landform models became apparent and were the basis for the soil maps and the development of the soil series and map unit descriptions. The soil-landform relationships for this survey area are discussed under the heading "Formation of the Soils:"

The survey area was mapped at two levels of intensity. At the less detailed level, map units are mainly associations and complexes. The average size of the delineations for most management purposes was 160 acres. Most of the land mapped at this level is used as woodland and rangeland. At the more detailed level, map units are mainly consociations and complexes. The average size of the delineations for purposes of management was 40 acres, and the minimum size was 5 acres. Most of the land mapped at the more detailed level is used as irrigated and nonirrigated cropland. Spot symbols were used for contrasting soil types and miscellaneous areas that are too small to be mapped at the same intensity as the surrounding land. Inclusions of contrasting soils or miscellaneous areas are described in the map unit if they are a significant component of the unit.

Soil mapping in the high desert of eastern

Deschutes County and around the Cline Buttes area of western Deschutes County was completed by the Bureau of Land Management in the period 1978 to 1980. Some revision of the original series and map units occurred during this survey to reflect a better understanding of the soils. The Forest Service assisted in the soil mapping of the Sisters and Bend Ranger Districts in the Deschutes National Forest.

Samples for chemical and physical analysis were taken from typical pedons of the major soils in the survey area. The analyses were made at the National Soil Survey Laboratory in Lincoln, Nebraska, and at the Oregon State University laboratory. The analyses provided data used in soil classification and in making interpretations for fertility and erodibility and for engineering and land use planning.

Productivity estimates were made for timber production, rangeland, and crop production. Woodland productivity was estimated by the National Resources Conservation Service and the Forest Service from data gathered at selected forested sites. Rangeland productivity was estimated for plots inside and outside the survey area. Agricultural crop yield data was estimated by the Cooperative Extension Service, Farm Services Agency, and individual farmers.

Soil Survey of Alpha County, Oregon

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Fieldwork by William Ferry, Mike Lamkin, Jerry Macdonald, Ron Myhrum, and Aimee Walker, Natural Resources Conservation Service; Terry Brock, Forest Service; and Larry Thomas, Bureau of Land Management

United States Department of Agriculture, Natural Resources Conservation Service, in cooperation with United States Department of Agriculture, Forest Service; United States Department of the Interior, Bureau of Land Management; and Oregon Agricultural Experiment Station

The UPPER DESCHUTES RIVER AREA includes private and public land in parts of Deschutes, Jefferson, and Klamath Counties. The northern part of the survey area is comprised of the western part of Jefferson County (excluding the Warm Springs Indian Reservation). The central part of the survey area is in Deschutes County, and it includes areas of land administered by the Forest Service and the Bureau of Land Management. The southern part of the survey area is an island comprised of the southern part of Deschutes County, near LaPine, extending into the northern part of Klamath County and south to Crescent and Gilchrist. The survey area includes about 1,540,000 acres.

A wide variety of landscapes make up the survey area. In the north is the plateau known as the Agency Plains, adjacent to the Deschutes River canyon. To the south are rolling hills and lava benches with deep gorges incised by the Deschutes and Crooked Rivers. Farther to the south are pumice flats and basins with scattered cinder cones. To the east are the basalt plateaus of the high desert. The western edge is made up of the glaciated toe slopes and valleys of the Cascade Mountains. Elevation ranges from 1,295 feet at the northernmost point in the survey area to 5,545 feet at Three Creek Butte. The average annual precipitation is about 8 to 70 inches.

The survey area includes almost all of the cultivated land in Jefferson and Deschutes Counties

and the major population centers in these counties. Bend and Madras, the county seats of Deschutes and Jefferson Counties, respectively, are in the survey area.

Recreation and tourism, wood products, farming and ranching, and manufacturing are the main industries. The survey area is adjacent to or very near three wilderness areas, and there are two ski areas just to the west of the survey area. Several lakes, streams, and rivers are in or near the area.

The major north-south highway on the eastern side of the Cascade Mountains, U.S. Highway 97, passes through LaPine, Bend, Redmond, and Madras. A major east-west artery, U.S. Highway 20, passes through Bend and Sisters. A municipal airport is in Redmond, and airstrips with facilities are in Madras, Bend, and Sunriver. The railroad transects the area, following much the same route as U.S. Highway 97.

This soil survey updates the survey of Deschutes Area, Oregon (USDA, 1958) and the interim survey of Brothers Area (USDI, 1983). It provides additional information and has larger maps, which show the soils in greater detail.

General Nature of the County

This section briefly discusses the history and development, physiography and drainage, and climate of the survey area.

History and Development

When Europeans first saw the area of the Upper Deschutes River, it was occupied by the Warm Springs and Northern Paiute Tribes. Long before that time, Klamath Lakes Indians had occupied much of what is now the southern part of the survey area. The Molalla Indians from the Willamette Valley area west of the Cascade Mountains seasonally traveled into central Oregon and the Deschutes River area to gather food. The Cayuse and Sahaptin Indians also seasonally migrated into the area from the region that is now northeastern Oregon (Zucker, 1983).

A treaty was signed in 1955 that brought the Warm Springs, Paiute, and Wasco Tribes together on the Warm Springs Indian Reservation. The Warm Springs and Wasco Indians had been neighbors (the Wasco Indians occupied the region around The Dalles), had similar cultures, and often intermarried. Both tribes fished, hunted, and gathered roots and berries for sustenance.

The pursuit of beaver pelts brought the first white men to the area of the Deschutes River. "Deschutes" is from the French "Riviere des Chutes," which means the river of the falls. The first white man to see the Upper Deschutes River and central Oregon was Peter Skene Ogden of the Hudson's Bay Company. He and his party set out from the Columbia River late in 1825 and headed up the Deschutes River, trapping as they went. When they came to what is now known as the Crooked River, they ventured upriver, eventually arriving in the John Day River area. They returned in 1826, heading down the White River and crossing the Deschutes River at Sherar's Falls. Again they headed up the Deschutes River to the Crooked River, and after following that channel, ventured into southeastern Oregon. On their return, they became the first white men to see what later became known as Newberry Crater, East Lake, and Paulina Lake (Bend Bulletin, 1991).

An exploration party under the command of Lt. Robert Williamson was sent west in 1855 to find the best route for a railroad to extend from the Mississippi River to the Pacific Ocean. Included in the party was John Strong Newberry, a physician and naturalist, whose name was given to the crater discovered in 1826. The expedition came from San Francisco by way of Klamath Falls. Their trek led them through the Deschutes River area, and they continued on to the Metolius River and Black Butte areas. They followed the Metolius River to the Cove Palisades and then crossed the Cascade Mountains.

Settlement in the area was discouraged, and in 1856 it was even forbidden by the Federal

government because of resistance to the presence of white men. The area to the north and east was settled first, particularly that near Shaniko, which was the end of the line for the railroad.

The Homestead Act of 1862 drew many optimists to the area, and even the high desert to the east was scattered with homesteaders. One by one, however, these would-be ranchers and farmers surrendered the land back to the sagebrush and moved on.

The Madras area was settled in the late 1860's. There was a rumor that a railroad was coming to this area, and settlers were drawn to the area because the soil was more fertile than that near Bend and Redmond.

Irrigation had several small beginnings in the 1870's in the Sisters, Bend, Redmond, and Madras areas. Rights to water from the Deschutes River were filed in the 1890's.

The ill-fated Tumalo Irrigation District was established in 1893, the Swalley Brothers Irrigation District in 1899, and the Arnold Irrigation District in 1904. The Pilot Butte Canal started carrying water in 1904, and it became part of the Central Oregon Irrigation District in 1910. In 1912 the North Canal began transporting water northward to Redmond. The Redmond area received irrigation water in 1906 and the Madras area in 1946. Presently, six irrigation districts use water from the Deschutes River.

Alfalfa, barley, oats, and potatoes were all grown in the earlier days in Deschutes and Jefferson Counties. Presently in Deschutes County, alfalfa is the main crop and there are relatively few acres of potatoes and mint. Almost all other irrigated land in the county is pasture. In Jefferson County, alfalfa, potatoes (mostly seed potatoes), grass seed, carrot seed, mint, and garlic are grown, making it a diverse and significant agricultural area.

Livestock in the survey area historically included only cattle and sheep. Today the livestock operations are comprised of cattle, llamas, horses, and sheep.

Timber land in the area has been bought since as early as 1898; however, until the railway was completed, the importance of lumber to the economy was limited. In 1916 the Shevlin-Hixon Mill was established, and the Brooks-Scanlon Mill was established soon after. According to Phil Brogan, by the late 1920's these mills were producing 500 million board feet of lumber annually and they employed about 2,000 workers. This helped to establish the economic base for Bend and the rest of central Oregon (Brogan, 1977). In spite of reduced timber harvesting, the wood products industry is still important to the economy of Deschutes and Jefferson Counties.

The survey area is known for its recreational appeal. Central Oregon offers opportunities for worldclass downhill and cross-county skiing, golfing, fishing, hunting, whitewater rafting, rock climbing, and hiking.

Physiography and Drainage

The approximately 1.5 million acres comprising the survey area includes parts of three major land resource areas-the Upper Snake River Lava Plains and Hills, the Eastern Slope of the Cascade Mountains, and the Malheur High Plateau (USDA, 1981).

Relief is moderate throughout the survey area. The topography of the Upper Snake River Lava Plains and Hills resource area is nearly level to rolling except for the deeply incised canyons of the Deschutes and Crooked Rivers and several widely scattered cinder cones. With the exception of the Deschutes and Crooked Rivers, perennial and intermittent drainageways are lacking because of the limited precipitation and runoff.

The topography of the Eastern Slope of the Cascade Mountains resource area is nearly level to steep. Perennial and intermittent drainageways are numerous because of the precipitation that falls in spring and fall and the continuous runoff from snowmelt.

The topography of the Malheur High Plateau resource area is nearly level to rolling except for the numerous cinder cones that dot the landscape. Perennial and intermittent drainageways are lacking in this resource area because of limited precipitation and runoff.

Most of the survey area is drained by the Deschutes River and its tributaries, which include the Little Deschutes River, Tumalo Creek, Dry River, Squaw Creek, Metolius River, Crooked River, and Willow Creek. Water is a limited resource in the agricultural areas of the survey area because of the limited precipitation, high infiltration rate, and moderate or rapid permeability of the soils.

Water from snowmelt is stored in Crane Prairie and Wickiup Reservoirs and is used for irrigation.

Climate

In this survey area, temperature and precipitation are related to changes in elevation. Elevation increases from the northern part of the area near Madras to the southern part near LaPine. The climate for the area was recorded at Madras, Bend, and Chemult during the period 1952 to 1990. The weather station at Chemult is outside the survey area, but the climate is representative of the LaPine area.

Table 1 gives data on temperature and precipitation. Table 2 shows probable dates of the first freeze in fall and the last freeze in spring. Table 3 provides data on length of the growing season.

The average monthly temperature at Madras, Bend, and Chemult is 48, 46, and 42 degrees F, respectively. The average temperature in summer (June, July, and August) is 64, 60, and 53 degrees, respectively. The average temperature in winter (December, January, and February) is 34, 33, and 28 degrees, respectively. The extreme temperatures at all three stations were about 102 degrees for the high and -27 degrees for the low.

Growing degree days, shown in table 1, are equivalent to "heat units." During the month, growing degree days accumulate by the amount that the average temperature each day exceeds a base temperature (40 degrees). The normal monthly accumulation is used to schedule single or successive plantings of a crop between the last freeze in spring and the first freeze in fall.

The average annual precipitation is 11 inches at Madras and Bend and 24 inches at Chemult. Most of the precipitation, about 70 percent, falls during November through April. During the driest months, which are July, August, and September, the average monthly precipitation is less than 1 inch. The amount and duration of snowfall in winter is variable, but the southern part of the area receives the highest amounts for the longest duration.

Land Capability Classification

Land capability classification shows, in a general way, the suitability of soils for most kinds of field crops. Crops that require special management are excluded. The soils are grouped according to their limitations for field crops, the risk of damage if they are used for crops, and the way they respond to management. The criteria used in grouping the soils do not include major and generally expensive landforming that would change slope, depth, or other characteristics of the soils, nor do they include possible but unlikely major reclamation projects. Capability classification is not a substitute for interpretations designed to show suitability and limitations of groups of soils for rangeland, for woodland, and for engineering purposes.

In the capability system (USDA, 1961), soils are generally grouped at three levels—capability class, subclass, and unit. Only class and subclass are used in this survey.

Capability classes, the broadest groups, are designated by numerals I through VIII. The numerals indicate progressively greater limitations and narrower choices for practical use. The classes are defined as follows:

Class I soils have few limitations that restrict their use.

Class II soils have moderate limitations that reduce the choice of plants or that require moderate conservation practices.

Class III soils have severe limitations that reduce the choice of plants or that require special conservation practices, or both.

Class IV soils have very severe limitations that reduce the choice of plants or that require very careful management, or both.

Class V soils are not likely to erode but have other limitations, impractical to remove, that limit their use.

Class VI soils have severe limitations that make them generally unsuitable for cultivation.

Class VII soils have very severe limitations that make them unsuitable for cultivation.

Class VIII soils and miscellaneous areas have limitations that nearly preclude their use for commercial crop production.

Capability subclasses are soil groups within one class. They are designated by adding a small letter, *e*, *w*, *s*, or *c*, to the class numeral, for example, IIe. The letter *a* shows that the main hazard is the risk of erosion unless close-growing plant cover is maintained; *w* shows that water in or on the soil interferes with plant growth or cultivation (in some soils the wetness can be partly corrected by artificial

drainage); *s* shows that the soil is limited mainly because it is shallow, droughty, or stony; and *c*, used in only some parts of the United States, shows that the chief limitation is climate that is very cold or very dry.

In class I there are no subclasses because the soils of this class have few limitations. Class V contains only the subclasses indicated by *w*, *s*, or *c* because the soils in class V are subject to little or no erosion. They have other limitations that restrict their use to pasture, rangeland, woodland, wildlife habitat, or recreation.

The capability classification of each map unit in this survey area is given in table 5.

Broad Vegetative Zones

Livestock and wildlife in the survey area graze and browse in a wide variety of environments that support varied vegetative cover types. These broad zones, which are characterized by the dominant soils and potential native vegetation, are discussed in this section.

Natural vegetation in the survey area varies greatly because of the wide range in climate and the contrasting topographic features. In addition, an extensive mantle of ash and pumice covers much of the area. The soils have low inherent fertility, higher than expected available water capacity, and thermal properties that are less conducive to heat transfer.

From the high, moist, cold soils of the Cascade Mountains eastward to the dry, cool soils of the lava plains, known as the High Desert, climate is associated with the major differences in the types of vegetation over short distances. Precipitation decreases from 70 inches in the forests of the Cascade Mountains to about 8 inches in the Madras and Redmond areas. Soils that are influenced by ash and pumice extend nearly to the eastern boundary of the survey area.

From north to south in the survey area, there is a gradual decrease in temperature, increase in moisture, and increase in elevation. The warmer, lower elevations at the northern end of the area have the longest growing season. The soils have little ash and pumice influence except in some local deposits. The area south of Juniper Butte to Bend and west to Hampton has been influenced significantly by volcanic ash from Mt. Mazama. Soil temperatures in this zone become cooler as the content of ash and the elevation increase.

In the area south of Bend, the thickness of the ash and pumice mantle increases significantly. Temperatures are cold, and freezing temperatures may occur at any time during the year. The vegetation near Bend consists of ponderosa pine plant

communities, and in the LaPine Basin it consists of lodgepole pine plant communities.

Mixed Conifer Zone. This zone is characterized by general soil map units 15 and 20. The forests commonly include various combinations of white fir, Douglas fir, ponderosa pine, incense cedar, and some lodgepole pine. The dense stands generally are not grazed by livestock unless the overstory canopy is opened by fire or logging. Forage is sparse in areas where there is an abundance of unpalatable evergreen shrubs such as chinkapin, snowbrush, manzanita, and Oregon grape. This zone traditionally has been used as summer range for both livestock and big game. It is characterized by cold temperatures in winter and cool temperatures in summer, and it receives the highest amount of precipitation of any part of the survey area. Deep snow commonly is on the ground throughout winter, and it remains until late in spring or early in summer. New plant growth occurs very late.

Ponderosa Pine Zone. This zone is characterized by general soil map units 14, 16, 18, and 19. Ponderosa pine forests are at the lower elevations and in areas that receive less precipitation than the adjacent mixed conifer zone. The ponderosa pine zone has two very distinct subdivisions based on understory vegetation. Manzanita and snowbrush are prominent in the understory of the cooler, more moist area adjacent to the mixed conifer zone. Antelope bitterbrush is dominant in the understory in the warmer, drier area adjacent to the sagebrush juniper zone. Forage is readily available throughout the ponderosa pine zone because of the abundance of palatable species such as Idaho fescue, bottlebrush squirreltail, needlegrass, Ross sedge, and antelope bitterbrush. This zone has a natural open overstory canopy, which allows light to reach the understory. As a result, palatable species are abundant and the zone is suited to grazing even with minimal forest management or harvesting.

Lodgepole Pine Zone. This zone is dominant in the LaPine Basin. It is characterized by general soil map units 2 and 3 and the associated meadows in general soil map unit 1. This very cold lava plain has very deep and deep deposits of pumice and ash and has interspersed buttes and low ridges. Lodgepole pine forests are dominant on the toe slopes and lower lying flat areas that are affected by cold air drainage. Wet basins and poorly drained areas along the Upper Deschutes River system are associated with a variety of riparian communities. Higher lying areas on buttes and uplands support ponderosa pine forests and some mixed conifer forests.

Forage production is very high in the meadows in this zone. The pine forests, however, are less suited to grazing by livestock because of the scarcity of water

and the very low production of herbaceous vegetation. These forests support a variety of understory shrubs, including dominantly antelope bitterbrush along with wax currant and in some places manzanita, bearberry, and squawcarpet. Herbaceous cover consists primarily of western needlegrass, bottlebrush squirreltail, Ross sedge, and Idaho fescue.

Sagebrush Juniper Zone. The sagebrush juniper zone is characterized by general soil map units 4, 5, 6, 7, 8, 9, 10, and 17. Western juniper is a key species in the management of rangeland and woodland. The amount and density of western juniper has increased over the last 150 to 300 years. This increase has been attributed to the control of fire and possibly other factors such as overgrazing and changes in climate (USDA, 1997). Because range sites and associated plant species and composition are based on a climax plant community in which fire is considered to be a part of the ecosystem, western juniper is present on many soils in which it is not considered to be part of the historic climax plant community. Managers should compare the historic climax vegetative potential of a range or woodland site to the present-day vegetation. Suitable management alternatives depend on the objectives and goals of the land managers.

Within the sagebrush juniper zone, there are three important subdivisions based on soil properties. The southern part of the zone is strongly influenced by ash. It is characterized by general soil map units 5, 6, 8, and 17. The primary shrub species are mountain big sagebrush, rabbitbrush, desert gooseberry, and buckwheat. In areas that receive more than about 10 inches of precipitation, antelope bitterbrush commonly is the dominant shrub. The dominant grasses in the southern part include Idaho fescue, needleandthread, bottlebrush squirreltail, Indian ricegrass, Ross sedge, and bluebunch wheatgrass. Idaho fescue is less abundant and needleandthread is more abundant in the areas that receive less precipitation. Grazing is limited by the lack of natural surface water for livestock and by the extensive network of lava outcroppings. Reestablishment of western juniper is very slow after trees are removed by fire or mechanical means.

The northern part of the zone has minimal ash influence except for some local accumulation in the lower lying positions. This part is characterized by general soil map units 4, 7, and 9. The primary shrub species are basin big sagebrush, antelope bitterbrush, gray horsebrush, rabbitbrush, and buckwheat. The main grasses are bluebunch wheatgrass, Idaho fescue, Thurber needlegrass, Sandberg bluegrass, and bottlebrush squirreltail. Winters are mild in this part, and spring growth begins earlier because the growing season is longer.

A small area in this zone is represented by more clayey soils that are not influenced by ash. This area is characterized by general soil map unit 10. The primary shrubs and grasses are similar to those in the northern part of the this zone. Western juniper is more invasive on these soils, and it regenerates quickly after disturbance or if protected from fire. Because the soils are clayey and the topography is steep, the risk of water erosion is higher in this area than in other parts of the survey area.

Sagebrush Zone. This zone is in the eastern part of the survey area, extending eastward from the crest of Horse Ridge. It is characterized by general soil map units 11, 12, and 13. Temperatures are colder and the growing season is shorter than in the sagebrush juniper zone to the west. The sagebrush zone traditionally has been used for livestock grazing late in spring and in fall.

General soil map unit 11 is in a basin that is subject to cold air drainage. This unit does not support western juniper. The vegetation is dominantly mountain big sagebrush, Idaho fescue, and needlegrasses. In the southwestern part of the unit, near Pine Mountain, antelope bitterbrush is also a major species. This unit receives only about 10 to 12 inches of precipitation, which typically is considered inadequate for Idaho fescue. However, the coarse-textured soils are high in content of ash and have a higher than expected available water capacity, which compensates for the lower precipitation and allows Idaho fescue to become dominant. Areas of this unit are interspersed with numerous small, clayey basins that are ponded during spring runoff and support silver sagebrush and with dry drainageways that support basin wildrye and basin big sagebrush.

General soil map unit 12 is on a lava plain. The soils are shallow and have a thin mantle of ash. Western juniper is dominant in the plant community. Low sagebrush and mountain big sagebrush are the dominant shrubs, and Idaho fescue is the dominant grass. Areas of this unit are interspersed with seasonally ponded, clayey basins that support silver sagebrush and sparse herbaceous cover. The extreme eastern part of unit 12, near Hampton, has very little ash influence and is subject to less cold air drainage than is unit 11. Because of the lower available water capacity and the slightly warmer temperatures, Wyoming big sagebrush and bluebunch wheatgrass are dominant in this part of the unit.

General soil map unit 13 is on hills. Western juniper is throughout much of this unit. Mountain big sagebrush is the dominant shrub, and Idaho fescue and needlegrasses are the dominant grasses.

Woodland Management and Productivity

By Craig M. Ziegler and Russ Hatz, foresters, Natural Resources Conservation Service

Forest land comprises about 30 percent of the survey area. It is concentrated in the southern and western parts of the area. A majority of the forest land is public land that is administered by the Forest Service. The remainder is owned by commercial timber companies and private landowners. Precipitation ranges from about 15 to 70 inches.

The forests in the southern part of the survey area are mainly in the LaPine Basin. Elevation in the basin ranges from about 4,000 to 5,000 feet or more. The soils are influenced by volcanic ash and pumice. At the southern end of the basin the deposits of volcanic ash and pumice are as much as 60 inches thick or more, and at the northern end they are about 24 inches thick. The soils are cold and are low in fertility. They have a high available water capacity, but they dry out very quickly early in the growing season. There are two main forest cover types in this part of the survey area—interior ponderosa pine and lodgepole pine (Society of American Foresters, 1980). The interior ponderosa pine type is on lava plains and hills. Many years of fire control have allowed lodgepole pine to become established in the understory. Areas of Lapine, Shanahan, and Steiger soils support this forest cover type. The lodgepole pine type is in lowlying or depressional areas on pumice-mantled lava plains. Cold air drainage is trapped in these areas, and the resulting frost is detrimental to ponderosa pine. Areas of Lapine, Shanahan, Steiger, Sunriver, Tutni, and Wickiup soils support this forest cover type.

The forests in the western part of the survey area are more diverse. The dominant forest cover type is interior ponderosa pine. It is at the lower elevations and in drier areas. Ponderosa pine is the dominant tree species, but Douglas-fir, western larch, white fir, and western juniper occur in lesser amounts. The interior Douglas fir and white fir cover types generally are at the middle elevations, and the lodgepole pine cover type is at the higher elevations. The soils in the western part also have been influenced by volcanic activity. The layers of pumice and ash are a few inches thick to more than 60 inches thick. The farther away the soils are from the Cascade Range, the thinner the layers of pumice and ash. The proximity of the soils to various volcanic events and the direction and velocity of the wind also influence the thickness of the pumice and ash. The soils in this part have moderate fertility and high available water capacity.

Several large wood products manufacturers are in

or near the survey area. Ponderosa pine, the most prevalent tree species, and Douglas fir and white fir are used for lumber, plywood, and wood chips. Lodgepole pine is used for wood chips, plywood, and fence posts. Dead lodgepole pine is used extensively for firewood.

Many diseases and insects affect the forests and can be a problem in individual stands of trees. Damage varies from year to year. The mountain pine beetle (*Dendroctonus ponderosae*) is very destructive to forests. Large numbers of lodgepole pine, the principal host, periodically are killed, and individual trees are killed annually. The pine engraver beetle also attacks pine species. The western spruce budworm (*Choristoneura occidentalis*) defoliates Douglas fir and white fir, dramatically reducing growth. The western pine beetle (*Dendroctonus brevicomis*) attacks larger pine trees, and the western pine shoot borer (*Eucosma sonomia*) attacks younger pine trees.

Dwarf mistletoe (*Arceuthobium* spp.) is one of the most destructive parasites that attacks ponderosa pine, Douglas fir, and western larch. Red ring rot (*Fomes pini*) is a disease that kills western larch and lodgepole pine. Shoestring root rot (*Armillaria mellea*) is a problem for pines under stress and for Douglas fir and true firs. Brown stringy rot (*Echinodontium tinctorium*) is a serious disease of Douglas fir and true firs.

Soil surveys are important to land managers as they seek ways to maximize the use of forest land. This survey provides to managers information that can be used to make sound management decisions. Table 7 can be used by woodland owners and forest managers in planning the use of the soils for wood crops. Only the soils suitable for wood crops are listed. Slight, moderate, and severe indicate the degree of the major soil limitations to be considered in management.

Sheet and rill erosion ratings refer to the probability of excessive erosion occurring as a result of operations that expose the soil. Forests that are burned or overgrazed are also subject to sheet and rill erosion. A slight rating indicates that no particular erosion-control measures are needed under ordinary conditions; moderate indicates that some erosion-control measures are needed; and severe indicates that extra precautions are needed to control erosion during most silvicultural activities.

Erosion hazard ratings are determined by considering the topography, the erodibility of a soil, and the local climate. Moderate and severe ratings may indicate the need to modify road construction,

use special harvesting systems, and use alternative site preparation techniques.

Cut and fill erosion ratings refer to the probability that damage will occur as a result of erosion from road cuts and fills. All cuts and fills should be seeded. A slight rating indicates that no other preventative measures are needed under ordinary conditions; moderate indicates that additional erosion-control measures, such as use of mulch and sediment traps, are needed under certain conditions; and severe indicates that additional erosion-control measures are needed under most conditions.

The texture of the surface layer and subsoil and the length and angle of the slope contribute to the extent of the cut and fill erosion. The risk of erosion is greater in areas where the cuts and fills are longer and the erodibility of the soil is higher.

Equipment limitation ratings refer to the limits on the use of equipment as a result of soil characteristics. A rating of slight indicates that equipment use normally is not restricted because of soil factors; moderate indicates a short seasonal limitation because of soil wetness, a fluctuating water table, or some other factor; and severe indicates a seasonal limitation, a need for special equipment, or a hazard in the use of equipment.

Steepness of slope, soil wetness, and the susceptibility of the soil to compaction are the main limitations for equipment use. As the gradient and length of the slope increase, use of wheeled equipment becomes more difficult. Tracked equipment can be used in some of the steeper areas, but cable yarding systems should be used in the steepest areas. Soil wetness, especially in areas of fine-textured material, can severely limit the use of equipment and make harvesting practical only during the dry period in summer.

Soil compaction ratings refer to the probability that damage will occur to the soil structure as a result of repeated use of equipment when the soil is wet or moist. Compaction should always be considered during silvicultural activities. A rating of slight indicates that the only special practices needed are use of designated skid trails and protection of the layer of duff; moderate indicates the potential need for extra precautions, such as use of cable yarding instead of ground skidding and seasonal restrictions on equipment use; and severe indicates the need for extreme caution and possibly some restorative activities, such as ripping or discing, following harvesting.

Thickness of the layer of duff, content of coarse fragments, texture, and plasticity are characteristics of

the soil that are considered in the compaction ratings. Compaction decreases air spaces in the soil; thus, air and water movement are reduced, which restricts root growth and increases the risk of surface erosion.

Soil displacement ratings refer to the soil being gouged, scraped, or pushed from its natural position by mechanical means. Soil displacement is most often associated with mechanical slash disposal and site preparation. A *slight* rating indicates that equipment use is not restricted and that special precautions generally are not needed; *moderate* indicates that specialized equipment, such as a brush rake, should be used; and *severe* indicates that extreme caution is needed if mechanical slash disposal and site preparation are used.

Soil characteristics considered in the soil displacement ratings are thickness of the layer of duff, thickness of the surface layer, content of coarse fragments, and texture. Removing or mixing the layer of duff and exposing the mineral soil are necessary for natural regeneration of many species. If excessive soil displacement has occurred, however, plant recovery rates may be impaired. Because of the inherent low fertility of material influenced by pumice and ash, most of the nutrients and organic matter are in the upper few inches of the mineral soil. Prolonged exposure may increase the risk of erosion and further deteriorate the site.

Seedling mortality ratings refer to the probability of death of tree seedlings because of soil characteristics or topographic conditions. Plant competition is not considered in this rating. The ratings apply to healthy, dormant seedlings from good stock that are properly planted during a period of sufficient moisture. A rating of *slight* indicates that no problem is expected under normal conditions; *moderate* indicates that some problems can be expected and extra precautions are needed; and *severe* indicates that mortality will be high and extra precautions are needed for successful reforestation.

Soil wetness, droughtiness, and topographic conditions contribute to seedling mortality. To overcome these limitations, larger than normal planting stock, special site preparation, surface drainage, or reinforcement plantings may be needed.

Windthrow ratings refer to the soil characteristics that affect the development of tree roots and the ability of the soil to hold trees firmly. A rating of *slight* indicates that trees normally are not blown down by the wind; *moderate* indicates that an occasional tree may be blown down during periods when the soil is wet and winds are moderate or strong; and *severe* indicates that many trees may be blown down during

periods when the soil is wet and the winds are moderate or strong.

Restricted rooting depth because of a high water table, underlying bedrock, or an impervious layer and poor anchoring of roots because of loose soil material are the main factors contributing to the windthrow hazard. Moderate and severe ratings indicate the need for care in thinning forest stands, periodic salvage of windblown trees, and adequate roads and trails to allow for salvage operations.

Plant competition ratings refer to the likelihood of the invasion of undesirable plants when openings are made in the tree canopy. A *slight* rating indicates that unwanted plants are not likely to retard the development of natural or planted seedlings; *moderate* indicates that competition will retard the development of natural or planted seedlings; and *severe* indicates that competition can be expected to prevent the development of natural or planted seedlings.

Favorable climate and soil characteristics result in plant competition problems. In many cases, the key to predicting plant competition is the quantity and proximity of seed sources of undesirable plants or the quantity of unwanted brush rootstock that will resprout after harvesting. Moderate and severe ratings indicate the need for careful and thorough site preparation and the potential need for mechanical or chemical treatment to retard the growth of competing vegetation.

Fire damage ratings refer to the probability that a fire of moderate fireline intensity (116 to 520 Btu's/sec/ ft) will have a negative impact on the characteristics of the soil. A rating of *slight* indicates that negative impacts are not expected; *moderate* indicates that negative impacts, such as nonwettability and excessive erosion, may occur and extra caution is needed in planning prescribed fires; and *severe* indicates that negative impacts are likely to occur and extreme caution is needed in planning prescribed fires.

Thickness of the layer of duff, content of organic matter, and texture are soil characteristics considered in determining the ability of soil to resist fire damage. It may be necessary to burn in winter, use alternative lighting techniques, monitor the moisture content of the fuel, yard unmerchantable material, eliminate prescribed fires, or use erosion-control measures following burning.

In table 8, the potential productivity of forested soils is expressed as site *index*. The site index is the average height dominant and codominant trees will attain at a base age. For example, a site index of 70 (50-year base age) means that the dominant and codominant trees will reach an average height of 70 feet in 50 years and a site index of 120 (100-year base

age) means that the dominant and codominant trees will reach an average height of 120 feet in 100 years.

While it seems logical that a soil with a site index of 90 is more productive than a soil with a site index of 70, such a conclusion can be made only if the same tree species are compared and if the site indexes were derived from the same equations or tables. The tables used to compute site index vary according to species, and more than one site index table can be used for an individual species. Any given soil may have more than one site index, depending on the number of species the soil supports. Several publications were used to determine site index for this survey area (Alexander, 1967a; Alexander, 1967b; Cochran, 1979a; Cochran, 1979b; Haig, 1932; Meyer, 1961; Schmidt, 1976).

To facilitate comparing the potential productivity of different soils, the table includes values for potential wood production expressed as total *yield (board feet per acre)* and *annual growth (cubic feet per acre)*. Estimates of volume are calculated at the culmination of the mean annual increment (CMAI). The annual amount of wood fiber produced by a stand of trees changes as the stand matures. Very little wood fiber is produced when the trees are small, but the amount increases rapidly as the trees approach physiological maturity. Once trees reach maturity, the annual growth rate begins to slow. CMAI is the estimated age at which a fully stocked stand achieves its highest average annual growth rate. It is the most efficient time to harvest as far as tree growth is concerned. Other factors, such as stumpage values, cost effectiveness, and management objectives, also should be considered in determining the best time to harvest.

As an example of how the table can be used, consider the Allingham soil in detailed soil map unit 4C. A fully stocked stand of ponderosa pine on this soil has a site index of 77; that is, the average height of the dominant and codominant trees at age 100 is 77 feet. If the stand is allowed to grow for 160 years, the predicted yield will be 33,400 board feet per acre. However, the stand will attain its maximum annual production of wood fiber (64 cubic feet per acre per year) at age 50.

The species under *common trees* that are indicated by a footnote notation are ones that are recommended for planting and are most suitable for commercial wood production.

Woodland Understory Vegetation

The detailed soil map units in this survey area have been correlated to a range site or plant association. The site or association, such as South 9-12pz or CDS6-13, respectively, is given at the end of each map

unit description. For those map units or components assigned to a range site, the vegetative information on production, characteristic vegetation, and composition is given in table 6. For those map units or components assigned to a plant association, the vegetative information on characteristic vegetation and composition is provided in the publication "Plant Associations of the Central Oregon Pumice Zone" (USDA, 1985).

Engineering Index Properties

Table 15 gives estimates of the engineering classification and of the range of index properties for the major layers of each soil in the survey area. Most soils have layers of contrasting properties within the upper 5 or 6 feet.

Depth to the upper and lower boundaries of each layer is indicated. The range in depth and information on other properties of each layer are given for each soil series under the heading "Soil Series and Their Morphology."

Texture is given in the standard terms used by the U.S. Department of Agriculture. These terms are defined according to percentages of sand, silt, and clay in the fraction of the soil that is less than 2 millimeters in diameter. "Loam," for example, is soil that is 7 to 27 percent clay, 28 to 50 percent silt, and less than 52 percent sand. If the content of particles coarser than sand is as much as about 15 percent, an appropriate modifier is added, for example, "gravelly." Textural terms are defined in the Glossary.

Classification of the soils is determined according to the Unified soil classification system (ASTM, 1993; PCA, 1973) and the system adopted by the American Association of State Highway and Transportation Officials (AASHTO, 1986; PCA, 1973).

The Unified system classifies soils according to properties that affect their use as construction material. Soils are classified according to grain-size distribution of the fraction less than 3 inches in diameter and according to plasticity index, liquid limit, and organic matter content. Sandy and gravelly soils are identified as GW, GP, GM, GC, SW, SP, SM, and SC; silty and clayey soils as ML, CL, OL, MH, CH, and OH; and highly organic soils as PT. Soils exhibiting engineering properties of two groups can have a dual classification, for example, CL-ML.

The AASHTO system classifies soils according to those properties that affect roadway construction and maintenance. In this system, the fraction of a mineral soil that is less than 3 inches in diameter is classified in one of seven groups from A-1 through A-7 on the basis of grain-size distribution, liquid limit, and

plasticity index. Soils in group A-1 are coarse grained and low in content of fines (silt and clay). At the other extreme, soils in group A-7 are fine grained. Highly organic soils are classified in group A-8 on the basis of visual inspection.

Rock fragments larger than 10 inches in diameter and 3 to 10 inches in diameter are indicated as a percentage of the total soil on a dry-weight basis. The percentages are estimates determined mainly by converting volume percentage in the field to weight percentage.

Percentage (of soil particles) passing designated sieves is the percentage of the soil fraction less than 3 inches in diameter based on an oven-dry weight. The sieves, numbers 4, 10, 40, and 200 (USA Standard Series), have openings of 4.76, 2.00, 0.420, and 0.074

millimeters, respectively. Estimates are based on laboratory tests of soils sampled in the survey area and in nearby areas and on estimates made in the field.

Liquid limit and plasticity index (Atterberg limits) indicate the plasticity characteristics of a soil. The estimates are based on test data from the survey area or from nearby areas and on field examination.

The estimates of grain-size distribution, liquid limit, and plasticity index are generally rounded to the nearest 5 percent. Thus, if the ranges of gradation and Atterberg limits extend a marginal amount (1 or 2 percentage points) across classification boundaries, the classification in the marginal zone is omitted in the table.

Classification of the Soils

The system of soil classification used by the National Cooperative Soil Survey has six categories (USDA, 1975; USDA, 1992). Beginning with the broadest, these categories are the order, suborder, great group, subgroup, family, and series. Classification is based on soil properties observed in the field or inferred from those observations or from laboratory measurements. Table 18 shows the classification of the soils in the survey area. The categories are defined in the following paragraphs.

ORDER. Eleven soil orders are recognized. The differences among orders reflect the dominant soil-forming processes and the degree of soil formation. Each order is identified by a word ending in *sol*. An example is *Andisol*.

SUBORDER. Each order is divided into suborders primarily on the basis of properties that influence soil genesis and are important to plant growth or properties that reflect the most important variables within the orders. The last syllable in the name of a suborder indicates the order. An example is *Xerand* (*Xer*, meaning dry, plus *and*, from *Andisol*).

GREAT GROUP? Each suborder is divided into great groups on the basis of close similarities in kind, arrangement, and degree of development of pedogenic horizons; soil moisture and temperature regimes; type of saturation; and base status. Each great group is identified by the name of a suborder and by a prefix that indicates a property of the soil. An example is *Vitrixerands* (*Vitri*, meaning glass, plus *xerand*, the suborder of the *Andisols* that has a xeric moisture regime).

SUBGROUP Each great group has a *typic* subgroup. Other subgroups are *intergrades* or *extragrades*. The *typic* subgroup is the central concept of the great group; it is not necessarily the most extensive. *Intergrades* are transitions to other orders, suborders, or great groups. *Extragrades* have some properties that are not representative of the great group but do not indicate transitions to any other taxonomic class. Each subgroup is identified by one or

more adjectives preceding the name of the great group. The adjective *Typic* identifies the subgroup that typifies the great group. An example is *Typic Vitrixerands*. An example of an *intergrade* subgroup is *Humic Vitrixerands*. The adjective *Humic*, meaning *humus*, indicates that the surface layer is enriched with organic matter.

FAMILY Families are established within a subgroup on the basis of physical and chemical properties and other characteristics that affect management. Generally, the properties are those of horizons below plow depth where there is much biological activity. Among the properties and characteristics considered are particle size, mineral content, soil temperature regime, soil depth, and reaction. A family name consists of the name of a subgroup preceded by terms that indicate soil properties. An example is *ashy over loamy, mixed, frigid Humic Vitrixerands*.

SERIES. The series consists of soils within a family that have horizons similar in color, texture, structure, reaction, consistence, mineral and chemical composition, and arrangement in the profile.

Soil Series and Their Morphology

In this section, each soil series recognized in the survey area is described. Characteristics of the soil and the material in which it formed are identified for each series. A *pedon*, a small three-dimensional area of soil, that is typical of the series in the survey area is described. The detailed description of each soil horizon follows standards in the "Soil Survey Manual" (USDA, 1951). Many of the technical terms used in the descriptions are defined in "Soil Taxonomy" (USDA, 1975) and in "Keys to Soil Taxonomy" (USDA, 1992). Unless otherwise indicated, colors in the descriptions are for dry soil. Following the *pedon* description is the range of important characteristics of the soils in the series.

The map units of each soil series are described in the section "Detailed Soil Map Units."

Formation of the Soils

Soil is a natural, three-dimensional body on the earth's surface that supports plants. Its characteristics and properties are determined by physical and chemical processes that result from the interaction of five factors-parent material, climate, time, relief, and plant and animal life.

The influence of each factor varies from place to place, and some factors are more dominant than others. The interaction of all the factors determines the kind of soil that forms. Most of the differences in the soils in this survey area are the result of three factors-parent material, climate, and relief.

Parent Material

The characteristics of the parent material in which soils form have a profound initial impact on soil properties. Texture, permeability, bulk density, and fertility of young soils are affected by the nature of the parent material. The influence of parent material on soil formation and development decreases over time.

The soils in this survey area formed in material primarily of volcanic origin. Volcanic material, including basalt, andesite, rhyolite, tuff, pumice, and ash, is common. Substrata of volcanoclastic sediment, such as pumice, ash, and cinders, also are common, especially near the foot slopes of the Cascade Mountains. Soils underlain by glacial outwash and till are in the westernmost parts of Deschutes and Jefferson Counties.

The oldest geologic formations in the survey area, which are 25 to 50 million years old, are in the eastern part of Jefferson County and in small areas in the eastern part of Deschutes County (Baldwin, 1976). The degree of soil development on the John Day and Clarno Formations reflects long periods of geologic time. The Simas and Tub soils have a high content of clay, most of which has high shrink-swell potential such as does montmorillonite; an argillic or calcic horizon, or both; and high chroma.

Fluvial and lacustrine sediment of the Deschutes Formation, which was deposited 2 to 6 million years ago, underlies much of the Deschutes Basin, from Bend north to Gateway in the northwestern part of Jefferson County (Peterson et al., 1976). The

Deschutes Formation consists mainly of volcanic sand, gravel, and silt deposited in horizontal beds or reworked by wind and water. Included within the formation are welded tuff and interbedded lava flows that occur as rimrock on buttes and along canyon walls. The volcanic rock and sediment in the Deschutes Formation is from the Broken Top-Three Sisters area of the High Cascades. Preferential erosion has redeposited the unconsolidated material from the High Cascades onto the slopes of Green Ridge and into the Deschutes Basin (Smith, 1985). Superimposed over these areas is a mantle of volcanic ash deposited during the eruption of Mt. Mazama. The mantle is thickest in the southern part of the survey area and is thin and discontinuous in the northern part.

On Green Ridge, deep and moderately deep, soils such as those of the Gap, Glaze, Prairie, Windigo, and Smiling series, have layers of ash over fine-textured buried material derived from the underlying basalt or tuff. In the northeastern part of the survey area are soils that have a fine-textured subsoil, but they have little, if any, volcanic ash in the surface layer. Moderately deep and shallow soils, such as those of the Searles, Holmzie, Madras, and Agency series, are examples. Soils such as those of the Redcliff, Redslide, and Licksillet series formed along the margins of the rimrock in areas of colluvium and residuum derived from basalt. Era soils formed in old stream channel deposits. These soils are very deep and coarse textured and are underlain by sand and gravel of the Deschutes Formation.

In some areas are erosional remnants of lacustrine deposits of diatomite that have a rolling topography and predictable soil patterns. Buckbert soils, which are deep and medium textured, formed in the depressions containing sediment derived from the surrounding slopes. Lafollette soils are underlain by sand and gravel of the Deschutes Formation. These soils formed on the stream terraces in areas where a mantle of ash about 24 inches thick was blown in or washed in from the uplands. Tetherow soils, which are similar to the Lafollette soils, are underlain by cinders. The cinder cones west of Terrebonne, in the northern part of Deschutes County, are the source of this material.

The basalt flows near Bend and Redmond issued from vents in Newberry Volcano and High Cascades volcanoes. These flows are among the youngest surfaces in the survey area, having been laid down less than 2 million years ago. Soils on these flows are transitional between the coarse-textured pumice soils of the LaPine Basin and the finer textured soils in the northern part of the area. Varying amounts of volcanic ash have been moved from rock outcroppings and redeposited in depressions. Deschutes and Deskamp soils are in these depressions, and Stukel and Gosney soils are in the slightly higher positions along the margins of the depressions and rock outcroppings. Deskamp and Gosney soils are loamy sand because of their proximity to Mt. Mazama, but Deschutes and Stukel soils are dominantly sandy loam. Houstake soils are similar to the Deschutes soils except that they are deeper to basalt and have more cementation in the lower part of the profile. Statz soils, on older basalt lava flows, exhibit the most soil development. They have a well-developed, silica-cemented duripan.

Soils in the eastern part of the survey area (east of Horse Ridge) are distinctly different from those in the Cascade Range. The soils on plains, benches, and basins are moderately deep to very deep to bedrock or to a duripan. They are high in content of volcanic ash that originated from Newberry Volcano or Mt. Mazama. Soils of the Borobey, Gardone, Milcan, and Stookmoor series are examples. In contrast, the soils of the uplands formed in older material of the Pliocene and Pleistocene. These soils are shallow or moderately deep to bedrock or to a duripan. They typically do not have an influence of volcanic ash on the surface, but they have a fine- or medium-textured argillic horizon that is high in content of montmorillonite. Soils of the Ninemite, Menbo, and Beden series are examples. Lake sediment and windblown material accumulated in the smaller basins and playas. Soils such as those of the Swaler and Swalesilver series are in these basins and playas.

A large deposit of Mt. Mazama ash and pumice is within the broad LaPine Basin, between Newberry Volcano and the Cascade Mountains south of Bend. The basin was formed by basalt flows that dammed the Deschutes River near Benham Falls. The Deschutes and Little Deschutes Rivers meander through the area, indicating that the present base level has existed for a considerable period of time. The soils in this area are porous and have distinctive characteristics, such as low bulk density, low heat capacity, low thermal conductivity, and very high available water capacity. Permeability is rapid or very rapid. The thickness of the mantle of ash, depth to a

buried soil, and size of pumice fragments decrease as the distance from Mt. Mazama increases.

At the south end of LaPine Basin, the mantle of ash is as much as 10 feet thick. Lapine soils are on the uplands and pumice plains. These soils typically are coarse-textured ash and pumice throughout, and pumice fragments more than 2 millimeters in diameter make up much of the volume. Further north are the Steiger soils that are similar in texture to the Lapine soils, but they have fewer pumice fragments by volume. The Steiger soils have a loam or sandy loam buried soil at a depth of 40 to 60 inches or more. The Shanahan soils are at the northern end of the basin. These soils have a mantle of ash 20 to 40 inches thick over a buried soil, and the volume of pumice fragments is less than that of the Steiger soils.

Associated with the well drained to excessively well drained Lapine, Steiger, and Shanahan soils are the somewhat poorly drained Wickiup, Tutni, and Sunriver soils, respectively. These soils are on stream terraces between the drainageways and the uplands. They are similar in appearance to the upland soils except that they have mottles in the profile, which indicates the presence of a high water table at times during the year. Within the main drainageways of the Deschutes and Little Deschutes Rivers are poorly drained and very poorly drained soils that have a dark surface layer that varies in texture. These soils were laid down during flooding. Layers of volcanic ash are common in the profile. Another common feature is a layer of diatomite, which is a siliceous sedimentary material that formed from one-celled algae, called diatoms, and has low bulk density. These plants form in cold, shallow lacustrine environments that have a ready source of silica (Dixon and Weed, 1977).

At least three times in the last 100,000 years, glacial ice has covered the Cascade Mountains. The glacial moraines that formed were then blanketed with volcanic ash and cinders from local sources. The Bott and Minkwell soils typically have 24 inches of volcanic ash from High Cascades volcanoes and other sources over a buried soil of glacial till consisting of extremely cobbly or stony loam or clay loam. Soils such as those of the Belrick and Linksterly series have layers of distinctive scoria or fine ash, or both, from local sources, notably Blue Lake and Sand Mountain. Glacial outwash deposits consisting of cobbles, sand, and gravel have been incised locally by stream channels. These deposits form outwash fans and plains at the lower elevations. Soils that formed on these outwash deposits are differentiated by the thickness of the mantle of ash. The Allingham and Wizard soils typically have a cobbly, very cobbly, or very gravelly loam or clay loam buried soil at a depth

of 20 to 40 inches. The Circle and Suilodem soils have a similar buried soil at a depth of 40 to 60 inches. The Plainview and Tumalo soils formed in moderately extensive deposits of glacial outwash west of Tumalo. These soils are drier, and they exhibit less weathering of the ash than do the more moist Allingham, Wizard, Circle, and Suilodem soils.

Climate

The Cascade Mountains form the western boundary of the survey area and act as a barrier to airmasses moving in from the Pacific Ocean. These mountains separate western Oregon, which has a wetter and milder climate, from eastern Oregon, which has a drier, continental climate.

The two most commonly measured climatic factors influencing soil formation are precipitation and temperature. These factors determine the rate and type of physical and chemical reactions that occur in a soil. In general, precipitation and temperature affect soil development and behavior by controlling chemical reactions, physical processes, and the activity of soil organisms (Jenny, 1941).

Three distinct climatic zones based on temperature and precipitation are in the survey area. In the forested foot slopes of the Cascade Mountains, the mean annual precipitation ranges from about 80 inches near the crest of the Cascades to about 25 inches near Sisters. Most of the soils in this zone have a layer of ash or scoria derived from local sources and an underlying buried soil. The water passing through the soil leaches exchangeable bases from the surface layer into the subsoil and concentrates hydrogen and aluminum ions in the surface layer; therefore, reaction (pH) of the surface layer is neutral or slightly acid. These soils have a thin surface layer that is 2 percent organic matter or more. The plant community consists of conifers and evergreen shrubs that produce large amounts of material for decomposition. The rate of decomposition, however, is controlled by a combination of factors, such as cold soil temperature. The content of clay in the mantle of ash generally is quite low, usually less than 10 percent, but it increases dramatically in the soils that have a buried argillic horizon. These residual soils probably were formed in ash and basalt deposited when the climate was warmer and more humid.

To the east of the Cascade Mountains, the mean annual precipitation decreases rapidly. This is the transition zone separating the soils of the mountains from those of the desert. From Sisters east to about the Deschutes River, precipitation ranges from 18 to 25 inches. Soil temperatures are warmer in this zone

than in the mountains, reaction (pH) is near neutral throughout the profile, and total exchangeable bases is higher. The vegetation is dominantly shrubs and grasses with fewer conifers; thus, the content of organic matter is much lower. In some areas of rangeland, overgrazing by livestock has reduced the plant cover. In the soils that have a large amount of ash and pumice in the surface layer, fluctuations in the temperature of the surface layer are extreme. This is a result of the light color reflecting solar radiation and the low heat capacity of the porous pumice. The content of clay is low in these soils because the deposits are young, and the weathering of minerals is slow because of the lack of moisture.

The soils in the high desert in the eastern part of the survey area (east of Horse Ridge) have a mean annual precipitation of 8 to 12 inches. The vegetation is shrubs, grasses, and a few trees. The content of organic matter is low. Because of the low precipitation, total exchangeable bases is high and free carbonates occur as nodules in the profile and as coatings on the bedrock and coarse fragments. Reaction (pH) in the surface layer is neutral or slightly alkaline, and alkalinity increases as depth increases. The content of clay is low, and fluctuations in the soil temperature are extreme.

Time

The rate of soil formation is measured by the degree of soil horizonation. The influence of time is measured from "the point in time at which a pedologically catastrophic event is complete, initiating a new cycle of soil development" (Buol and others, 1973). The catastrophe may be geologic, such as deposition of new material on an existing soil or uplifting of a land mass, or climatic, such as a major change in environmental conditions. Human activity can also affect soil development.

With few exceptions, soil development in central Oregon can be traced from the Pliocene to the present, which covers a span of about 5 million years (Williams, 1976). Although uplift was already occurring in the Cascade Range, the formation of the High Cascades began with the growth of broad shield volcanoes during the beginning of the Pliocene. Basalt and andesite flows from these volcanoes contributed further to the separation of western and eastern Oregon along a north-south mountain belt. Flows of hot mud and ash and waterborne debris, such as sand, gravel, and boulders, swept down from the volcanoes onto the gentler slopes below. During the following millennia, the growth of the High Cascades continued and the climate changed to about what it is

at present. Conditions were favorable for weathering and translocating soil material. An argillic horizon formed in many soils until they were covered by layers of volcanic ash during the Pleistocene, beginning about 2 million years ago. Most notable and useful as a benchmark for measuring change was the eruption of Mt. Mazama about 6,600 years ago. Ash was deposited from south to north over most of central Oregon. Very little soil development has taken place in this mantle of ash. Thin A horizons have developed, and weakly developed B horizons are apparent from the increased structure (cambic horizon), weak cementation, and chemical weathering of the ash.

During the Pleistocene, large volumes of basalt from the High Cascades volcanoes and Newberry Volcano covered the landscape. Insufficient time has passed for development of horizons in this material. The typical profile of soils in these areas is a layer of ash over bedrock. Some soils have a weakly cemented to indurated duripan as a result of silica being leached and redeposited.

The LaPine Basin is a lake basin that formed as a result of lava flows damming the Deschutes River. It contains a broad expanse of Mt. Mazama pumice and ash deposited over stream or lake deposits of diatomite, peat, silt, and sand. Soil development is very slow because of the sterile nature of the pumice and ash and the cold soil temperatures. Thin A horizons have formed in this material, but there is no evidence of development of B horizons. The mantle of pumice and ash is more than 60 inches thick in the southern part of the basin, but it grades to about 24 inches thick near Bend.

Relief

Relief is the elevations or inequalities of the land surface (USDA, 1951). The main factors of relief taken into account are slope, aspect, elevation, and the site-specific microrelief features. These factors affect soil properties independently and in combination with the other factors of soil formation.

Relief has different effects under different environmental conditions. It modifies the influence of parent material and time affecting the erosion and deposition that takes place. It alters climate by increasing or decreasing effective moisture and temperature; consequently, the kinds and abundance of plants vary with aspect (Buol and others, 1973).

The Cascade Mountains have had a major influence on soil development in central Oregon. They alter the easterly movement of the moist, warm Pacific airmasses and create a rainshadow on the eastern slopes. Elevation in the survey area ranges from 2,500

feet near Madras in the northern part to nearly 5,000 feet in eastern part.

Slope gradient is an important factor in soil formation. The infiltration of water decreases and the amount of runoff increases as slope increases. Slope gradient and shape are related to the underlying lithology and its age. The broad basalt shield volcanoes of the High Cascades generally have moderately steep or steep slopes that rarely are more than 50 percent. The soils are deep and well drained. The outwash plains typically are gently sloping to strongly sloping. The soils are very deep and well drained and may or may not have discontinuities of gravelly outwash. Landforms of the Pliocene or older, such as Cline Buttes, Pine Mountain, and Juniper Butte, that are composed of andesite and rhyolite have the classic shape of older surfaces, including distinct convex, eroding upper slopes and concave, depositional lower slopes. Soils on the upper slopes may have a significant amount of cobbles and stones, while those on the lower slopes are deep and relatively free of stones. The canyons consist of cliffs, debris slopes, and fans (Williams, 1976). The thickness of the soils in the canyons is highly variable because of erosion and deposition, and areas of Rock outcrop and Rubble land are common. The plateaus that form the tops of the basalt flows are nearly level to moderately sloping and have stable surfaces. The soils on the plateaus are shallow to moderately deep and have a developed duripan or argillic horizon. Landforms throughout the survey area are modified by a mantle of volcanic ash that softens the appearance of the landscape.

Aspect, or the direction in which a slope faces, is another important feature of relief. Soils that formed on south-facing slopes usually are warmer and drier, have less biomass, and have a lower organic matter content in the surface layer than those on north-facing slopes.

An interesting phenomenon related to relief, found mainly in the LaPine Basin, is the difference in plant communities that occurs with minor changes in elevation. Frost pockets develop in the depressions because the cold air tends to follow the contour of the landscape. As a result, lodgepole pine grows in the depressions or low areas and ponderosa pine is the dominant species in the higher areas. Lodgepole pine seedlings are more tolerant of the cold temperatures at night and are tolerant of wetness in areas that have a high water table.

Plant and Animal Life

Plants and animals, including man, affect and are affected by the soils. The kinds of plants and animals

present also are influenced by the other soil-forming factors.

Soil micro-organisms decompose much of the dead plant material and aid in recycling nutrients into the soil. Earthworms, ants, and burrowing creatures mix soil horizons in areas of favorable moisture conditions.

Changes in vegetation in the survey area are the result of differences in elevation, temperature, and precipitation. The vegetation in the Cascade Mountains consists of commercial-grade timber species such as Douglas fir and ponderosa pine. Understory vegetation commonly consists of snowbrush, manzanita, and other shrubs and grasses. The decomposing litter results in dark-colored soils that have a thick organic layer on the surface and mineral horizons that are high in bases.

In the forest-range transitional areas, the tree

species consist of ponderosa pine and western juniper and the understory vegetation is mainly antelope bitterbrush and sagebrush. The relatively recent deposition of ash, the low precipitation, and the limited amount of organic material produce soils that have a low content of organic matter, are light colored, and have weak structure.

In the LaPine Basin, the soils on the terrace adjacent to the stream channel formed under a plant cover of willow, sedges, forbs, and grasses. These poorly drained soils have a thick organic surface layer over layers of pumice. The soils on the adjacent higher terrace are somewhat poorly drained and support lodgepole pine with an understory of bearberry, strawberry, and long-stemmed clover. These soils have a lower organic matter content than do the soils on the lower terrace.